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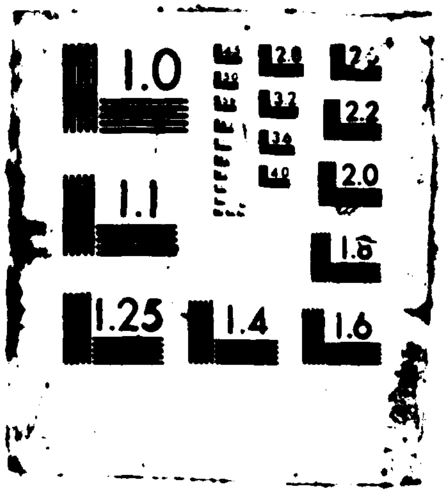
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The stick input has been analyzed during deliberate self-induced $+G_z$ loss of consciousness (G-LOC) on the USAF School of Aerospace Medicine human centrifuge. An F-16A stick was utilized with output of ± pitch, ± roll, an on-off binary sensory being obtained in 1/8-s intervals during G-LOC and recovery. The results are applicable to emerging aircraft autorecovery technology. The currently known physiologic aspects of G-LOC and their time relationship are reviewed in relation to the potential use of stick force as a rather simplistic G-LOC physiologic monitoring technique.

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F-16 CONTROL STICK RESPONSE DURING $+G_z$-INDUCED LOSS OF CONSCIOUSNESS

INTRODUCTION

The $+G_z$-induced loss of consciousness (G-LOC) results in absolute incapacitation of the pilot for an average of 12 s, followed by an additional 12 s of relative incapacitation (confusion), thus resulting in an average total incapacitation of 24 s. The total incapacitation represents the time the pilot would not be in control of his aircraft. Methods to usurp aircraft control, should G-LOC occur, require some type of aircrew monitoring to assure the earliest detection of incapacitation. Most techniques for physiologic monitoring of aircrew in the cockpit environment require complex instrumentation to determine pilot condition, are unduly encumbering, and are frequently unreliable in the constantly changing $+G_z$ aerial combat environment.

Since G-LOC is a current problem, with loss of aircraft and aircrew being a continuing daily threat, simplicity and ease of transition directly to the aircraft are primary requirements for ensuring the most rapid transfer of any physiologic monitoring system. The first step in assuring maximum fighter aircrew safety would naturally be to develop an autorecovery system that would prevent the aircraft from impacting the ground. This step has become a reality through the AFTI/F-16 gravity-induced loss of consciousness and spatial disorientation autorecovery system (1). This system allows input into the flight controls of a mean sea level (MSL) altitude, such that engagement of the autorecovery system is initiated by computation of aircraft speed, altitude, attitude, and the set MSL altitude which will not be violated. This system is perfect for training scenarios; however, continued improvement may be possible,especially for the combat environment. As compared with this type of autorecovery system, physiologic monitoring of the aircrewman has certain advantages, including: (a) potential enhancement of aircrew acceptance of computer usurption of aircraft control if definite incapacitation is detected; (b) earlier determination of incapacitation; and (c) no requirement for aircraft external radiating sensor, such as a radar altimeter.

The advanced fly-by-wire flight control system of the F-16 is interfaced with the pilot through a right-sided force sensing stick which is essentially non-mobile. Monitoring of this force input stick is a crude form of physiologic monitoring; but it has the advantage of not requiring additional encumbering equipment in the cockpit and, if reliable, is available for immediate development. The purpose of this report is to describe the human response to an F-16 stick during experimentally induced G-LOC on the USAF School of Aerospace Medicine (USAFSAM) centrifuge.

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(1) Howard, J. "AFTI/F-16 Gravity-induced Loss-of-consciousness and Spatial Disorientation Auto-recovery System." Proceedings of the IEEE National Aerospace and Electronics Conference,Dayton, Ohio, 1986, pp. 752-759.

METHODS

The USAFSAM centrifuge was configured as an F-16 cockpit, with a 30° tilt-back seat and an F-16A side-stick controller. The stick orientation (Fig. 1) was offset by 12°, so that direct negative pitch input was oriented backward and toward the pilot. A special binary on-off grip sensor was installed anteriorly on the stick, so that any positive grip on the stick placed the sensor on--with any relaxation of the grip returning the sensor to off. The functional stick allowed closed-loop control of the centrifuge, so that the centrifuge was driven by the subject. Closed-loop control allowed the subject to deliberately self-induce G-LOC. The subject followed a one-dimensional tracking task, using closed-loop control during the G-LOC induction. When unconsciousness was observed, the closed-loop control was decoupled so that stick input would continue to allow tracking, but would not control input of $+G_z$ into the centrifuge. Continual monitoring of the plus or minus pitch-and-roll input at 1/8-s intervals was performed throughout the centrifuge runs. The tracking profile, from the onset of $+G_z$, lasted 128 s.

Eight healthy experienced centrifuge subjects were exposed to very high onset (6 G/s) $+G_z$ (VHOG) for a planned 15 s at +7 G_z as the initial part of closed-loop centrifuge exposure. The subjects wore anti-G suits, but these were not inflated; and each subject was urged to remain as relaxed as possible. The VHOG exposure was sufficient to induce G-LOC, with the mean time to onset of G-LOC being 6.8 s. After G-LOC and recovery, the subject continued the tracking task using the F-16A stick; however, no $+G_z$ exposure resulted from the stick input. Each subject underwent two successive G-LOC exposures: one exposure required immediate return to +1 G_z, and one exposure required return to +2 G_z. Since no statistical difference was found for any of the physiologic or performance parameters between the +1 G_z and +2 G_z recovery runs, all data were included in this report without differentiation relative to the recovery $+G_z$ level.

RESULTS

The mean absolute incapacitation time for the G-LOC episodes was 12 s, with a mean relative incapacitation of 4 s, and a mean total incapacitation of 16 s. The mean response for all monitored responses for all subjects during all G-LOC episodes is shown in Figure 2. A typical individual response is shown in Figure 3. The individual responses for all G-LOC episodes relative to the binary on-off sensor are shown in Figure 4 (Parts a-d). From G-LOC to the occurrence of major convulsive (flail) movements of the upper extremities in the 6 subjects who suffered them, the mean time was 7 s.

EDITOR'S NOTE: For the convenience of the reader, all of the figures have been grouped at the close of this report.

CONCLUSIONS

Stick-force analysis has revealed that certain inputs have a high potential for utilization in monitoring the physiologic state of the pilot. This analysis specifically includes stick-force pitch input. Isolated roll input is not as brisk or definitive as pitch for G-LOC monitoring. The binary on-off sensor does reflect the period of unconsciousness in certain cases, but not in others. The sensor suffered from uncontrolled inputs resulting from convulsive movements, and frequently was initiated (post G-LOC) even though the subject was not able to track. The binary sensor was released, at least temporarily, during all G-LOC episodes and could, therefore, be of value in a comprehensive and integrative analysis of stick-force monitoring technology.

As an isolated parameter, stick pitch holds the most promise for monitoring the physiologic state of the pilot. The maximum pitch-and-roll inputs (N = 7) after the onset of the unconsciousness are shown in Figure 5. The range for pitch was -1.1 to -5.7 lb, and the range for roll was -1.4 to +7.7 lb. (Operational maximum stick input is ± 40 lb by design.) The maximum post-G-LOC inputs generally occurred coincident with the convulsive movements of the upper extremities, with resulting stick input, taking place during a time which we have described as the convulsion-prone period. This period occurs within the absolute incapacitation (unconsciousness) period, beginning at 7 s into the absolute incapacitation period and ending coincident with the return of consciousness. The convulsion-prone period, therefore, makes up the final 5 s of the 12-s absolute incapacitation period. The relative incapacitation period is virtually free of stick input until purposeful movement begins. The currently known G-LOC events and time relationship are shown in Figure 6.

Based on the F-16A stick inputs, the first potential physiologic autorecovery algorithm was constructed as shown in Figure 7. This algorithm, which is for illustrative purposes, forms the basis of further research directed toward understanding G-LOC, enhancing physiologic methods of autorecovery, and defining needed technology for completion of pilot recognition and recovery of G-LOC. Certain needed technology would include pilot interrogation and pilot warning. Initial efforts in this area include such visual and auditory inputs as master caution lights and auditory tones, used to measure the G-LOC incapacitation period. Further research is needed to refine these interrogation and warning techniques. Specifically, on the basis of present experimental results, the stick-force "window" for physiologic monitoring of G-LOC incapacitation is approximately ± 5 lb (pitch) during the first 12 s of incapacitation (absolute incapacitation), and is reduced to ± 1.5 lb (pitch) from return of consciousness (relative incapacitation) until purposeful movement capability is reestablished.

From these experiments and a long history of centrifuge G-LOC observation and videotape recording, it is obvious that the vast majority of G-LOC episodes are associated with complete stick release at some time during unconsciousness. Although some evidence does exist that an occasional individual will continue to have positive input into the stick, the overwhelming controlled experimental evidence indicates that the vast majority (if not the total) of G-LOC episodes are consistent with the results presented here.

Further data analysis, refinement of G-LOC physiologic monitoring algorithms, and enhanced methods of intervention hold promise for potentially increasing aircrew safety and performance.

F I G U R E S   1 - 7

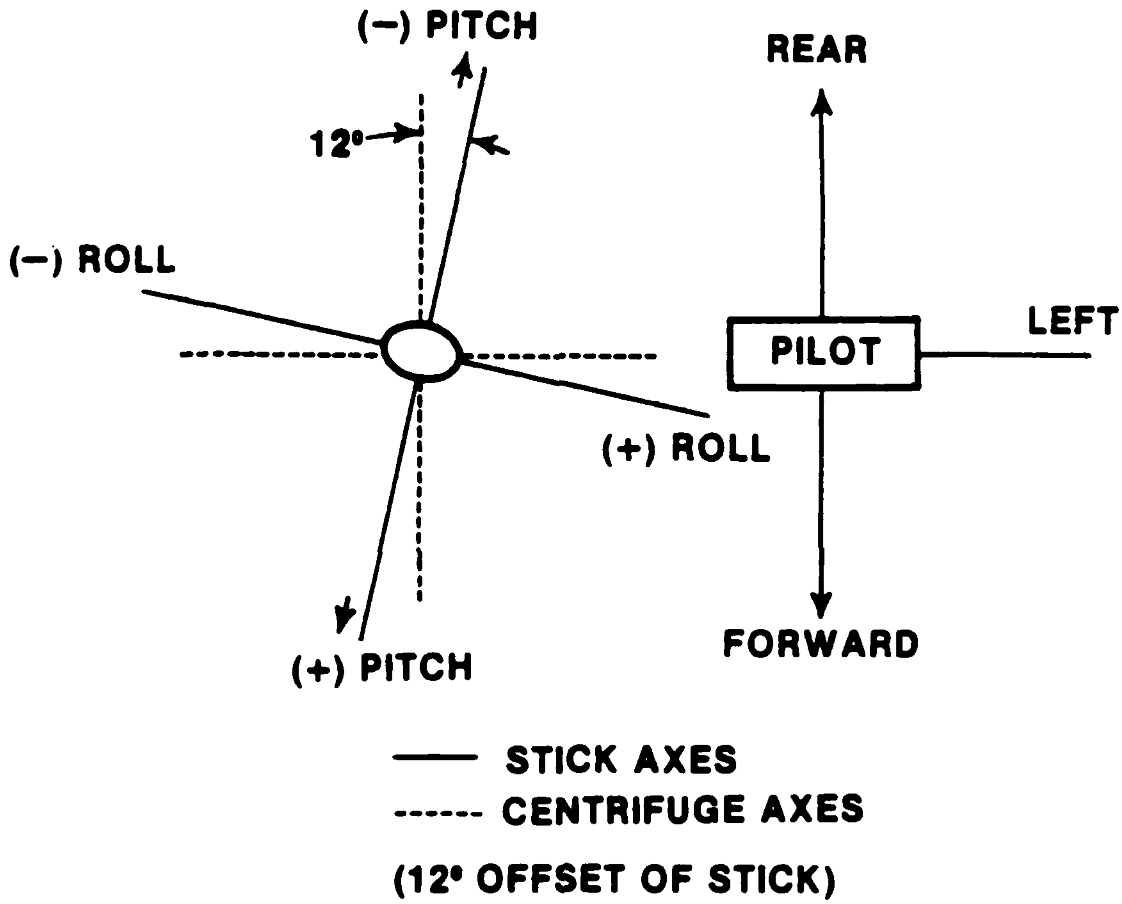


Figure 1. F-16A stick orientation relative to the pilot.

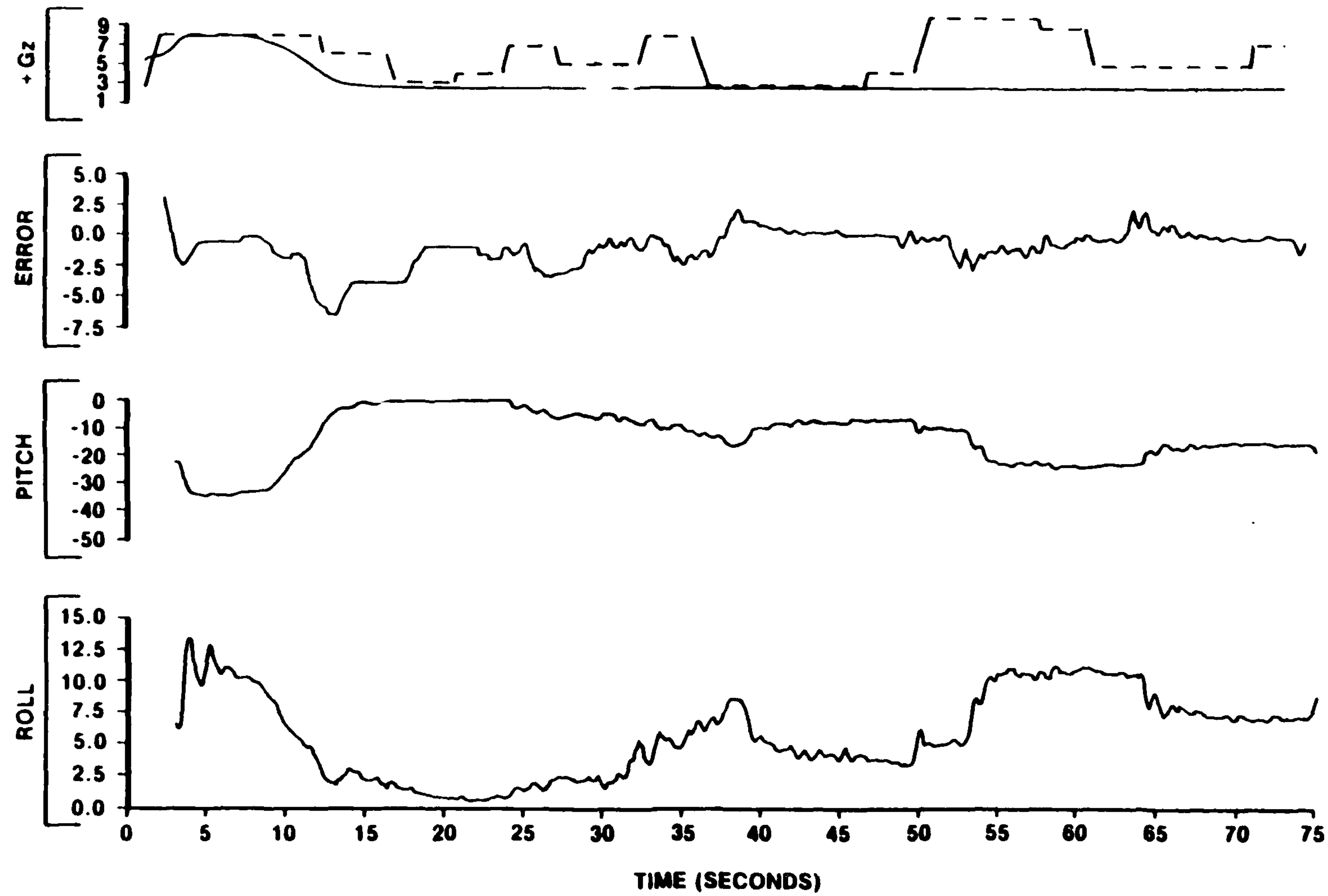


Figure 2. Mean response generated from all subjects during deliberate G-LOC episodes on the USAFSAM centrifuge. Parameters include: $+G_z$ level and tracking task; error score in G-units (difference between the tracking task profile and stick tracking); pitch input (lb); and roll input (lb).

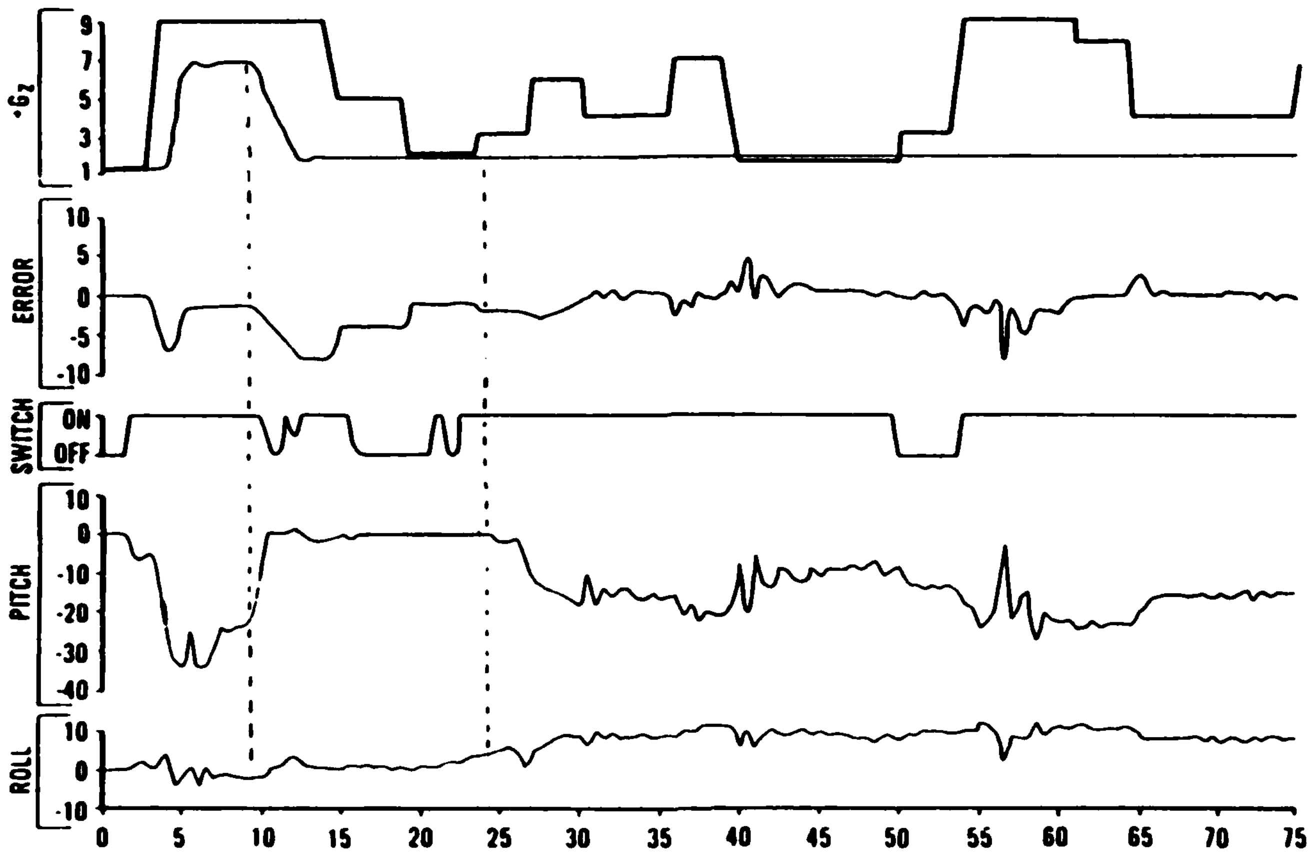
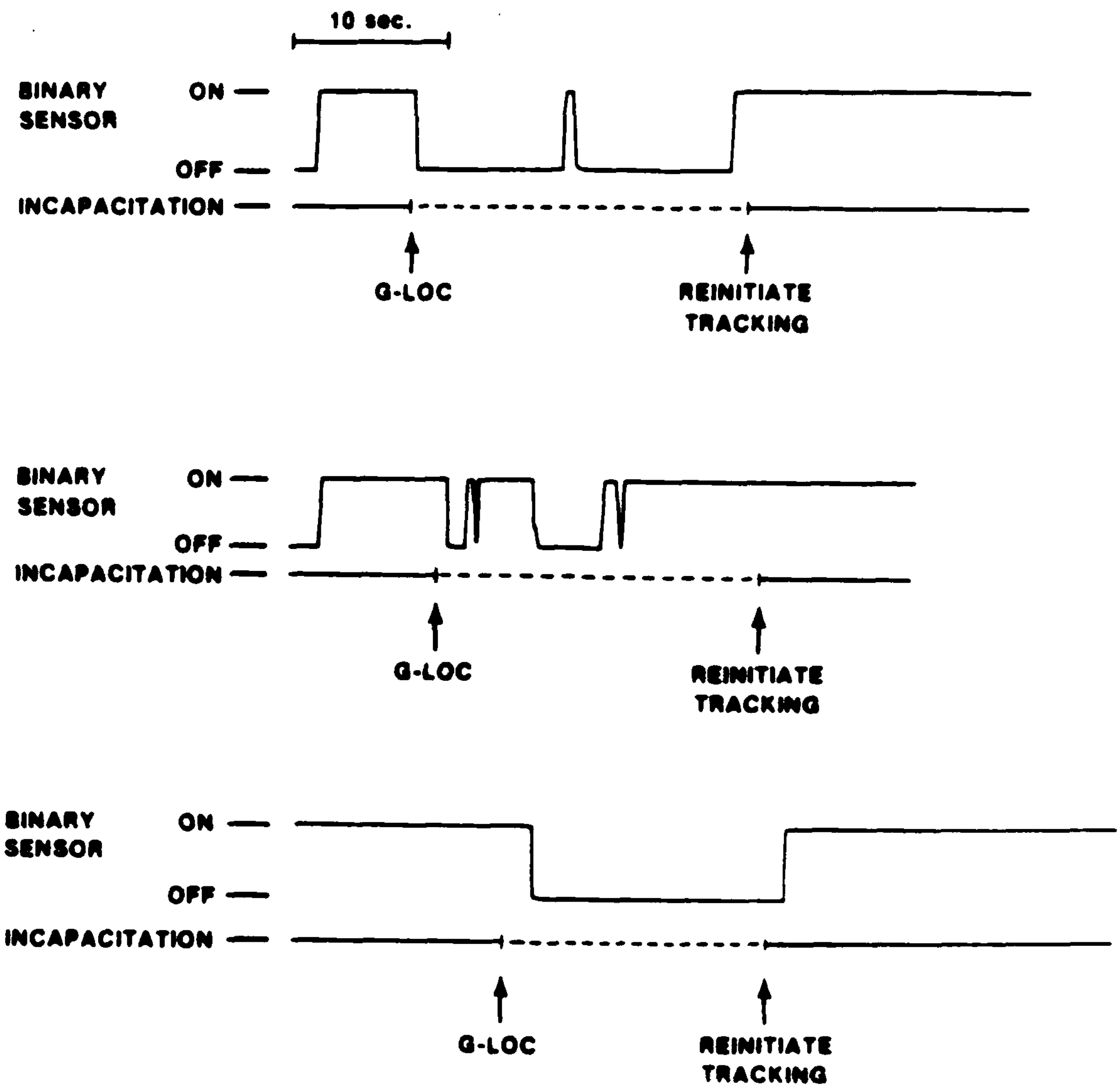


Figure 3. An individual response during deliberate G-LOC. Parameters include those shown in Figure 2, in addition to the response from a binary on-off switch installed anteriorly in the F-16A stick grip.



Part a

Figure 4: Parts a - d. Individual responses to a binary on-off F-16A grip switch during deliberate G-LOC episodes.

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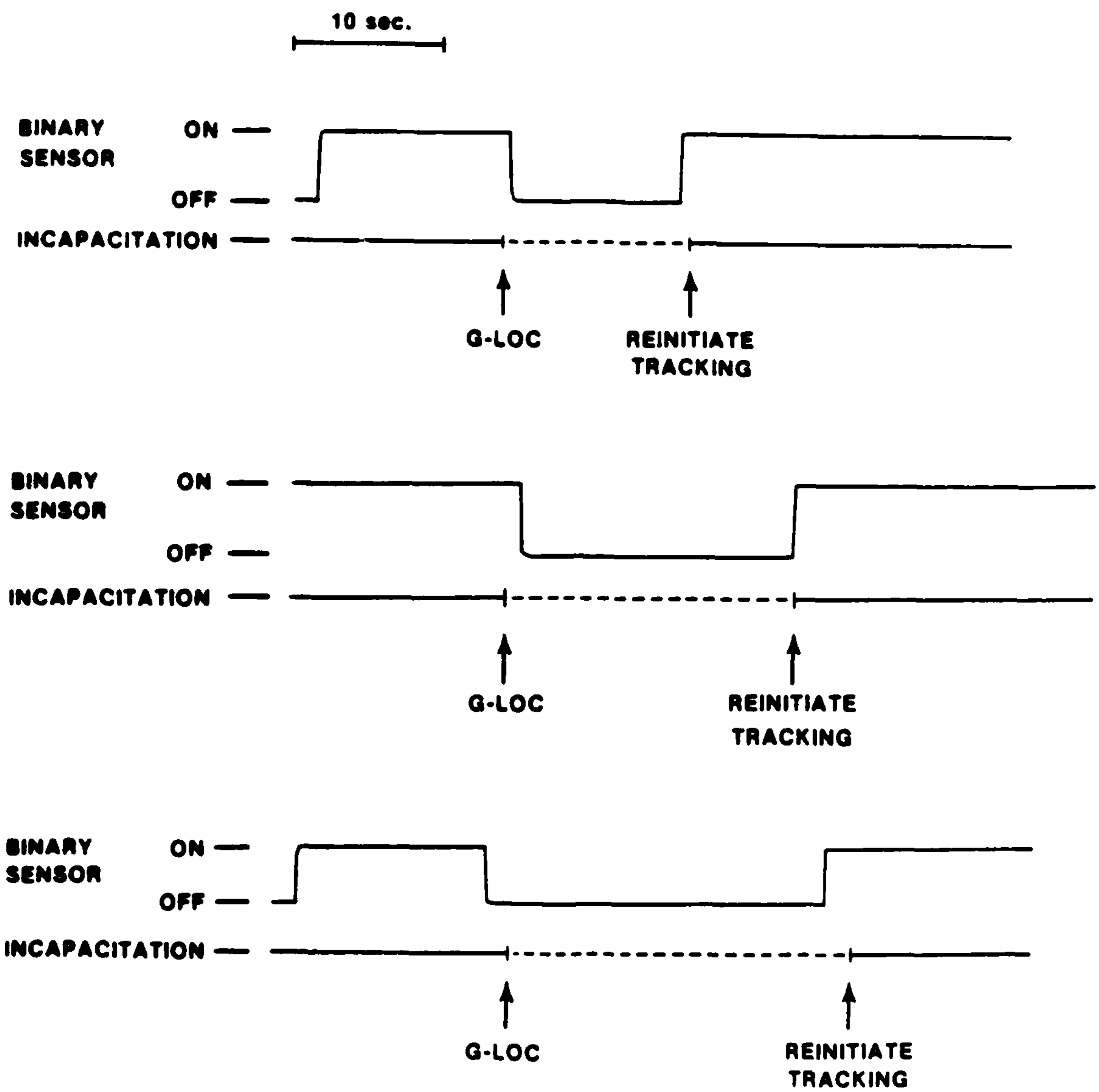

Figure 4: Part b

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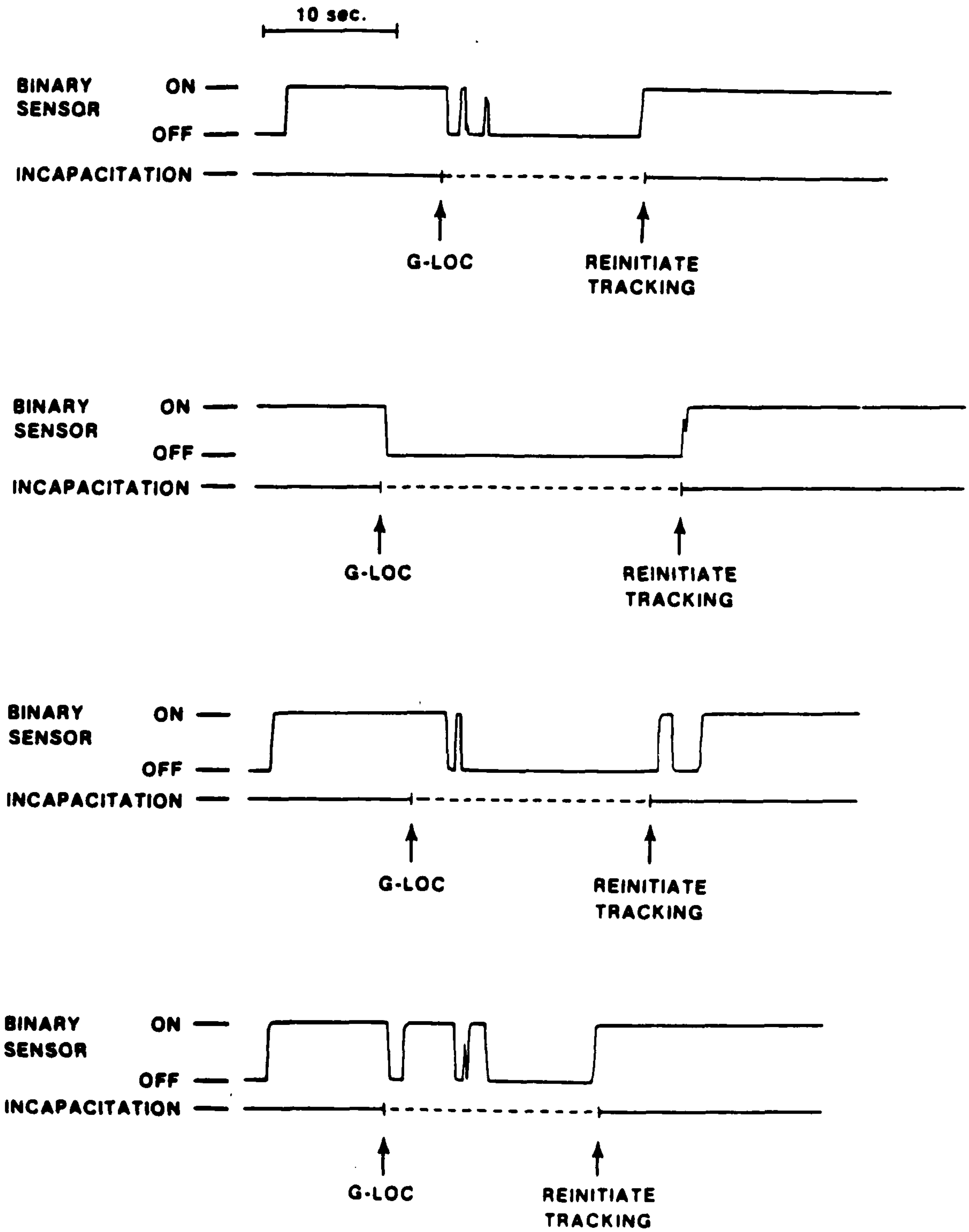

Figure 4: Part c

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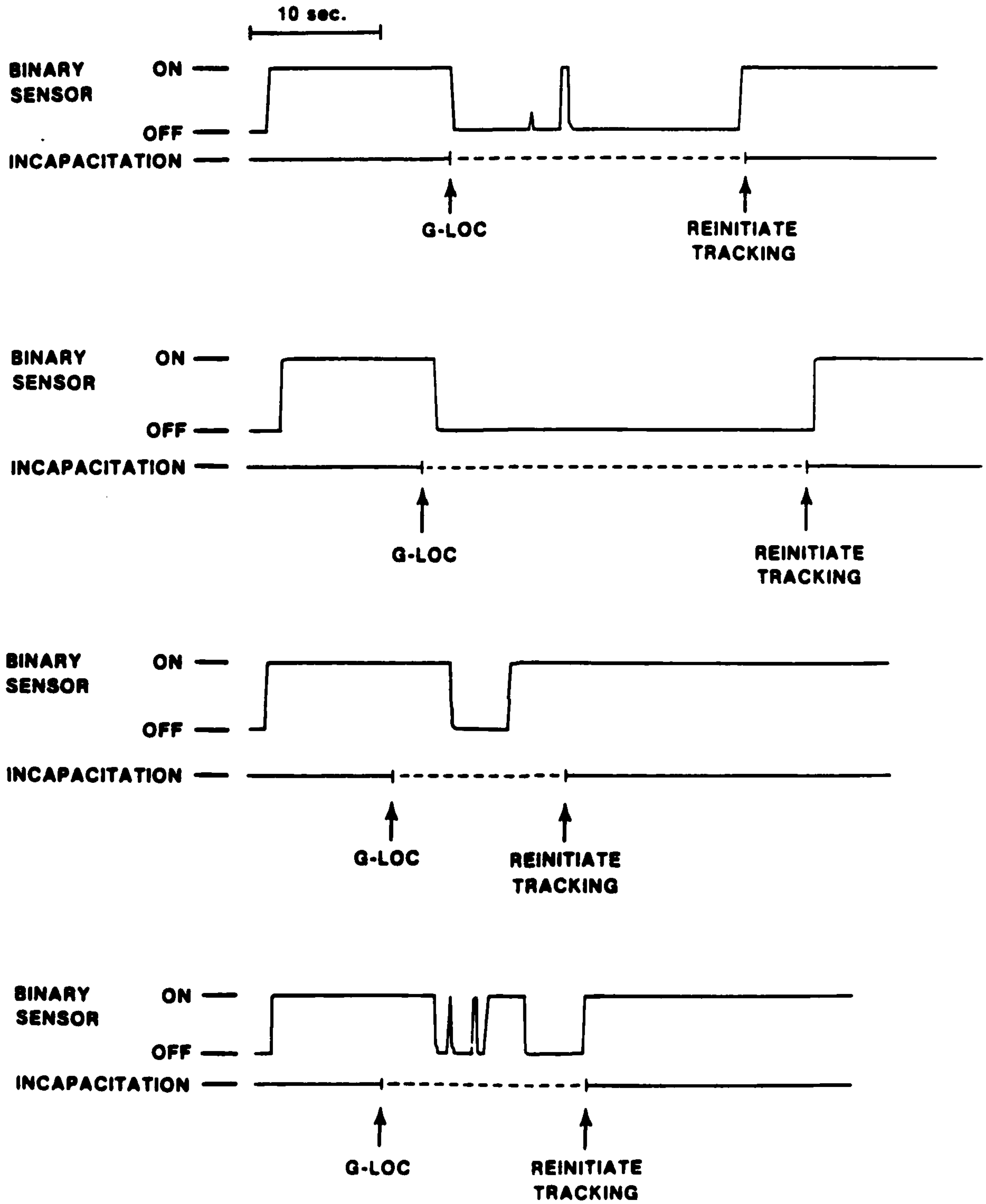

Figure 4: Part d

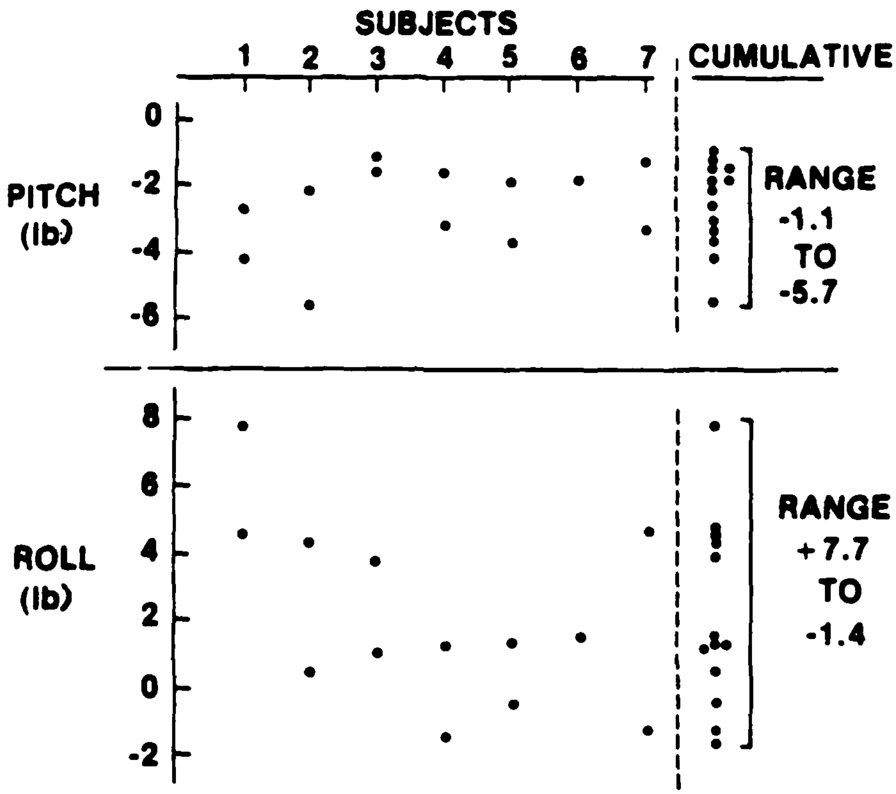

Figure 5. Individual maximum F-16A stick pitch-and-roll inputs during G-LOC.

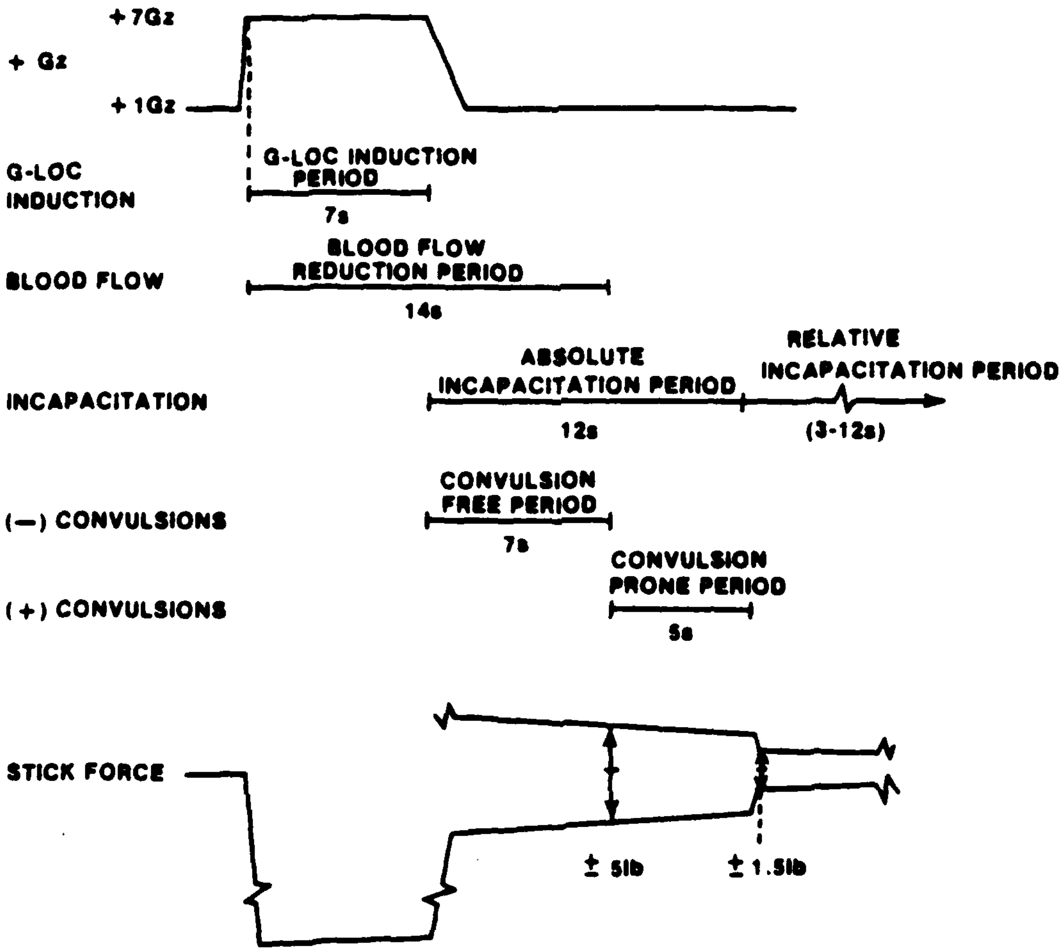

Figure 6. The currently known G-LOC events and their time relationships.

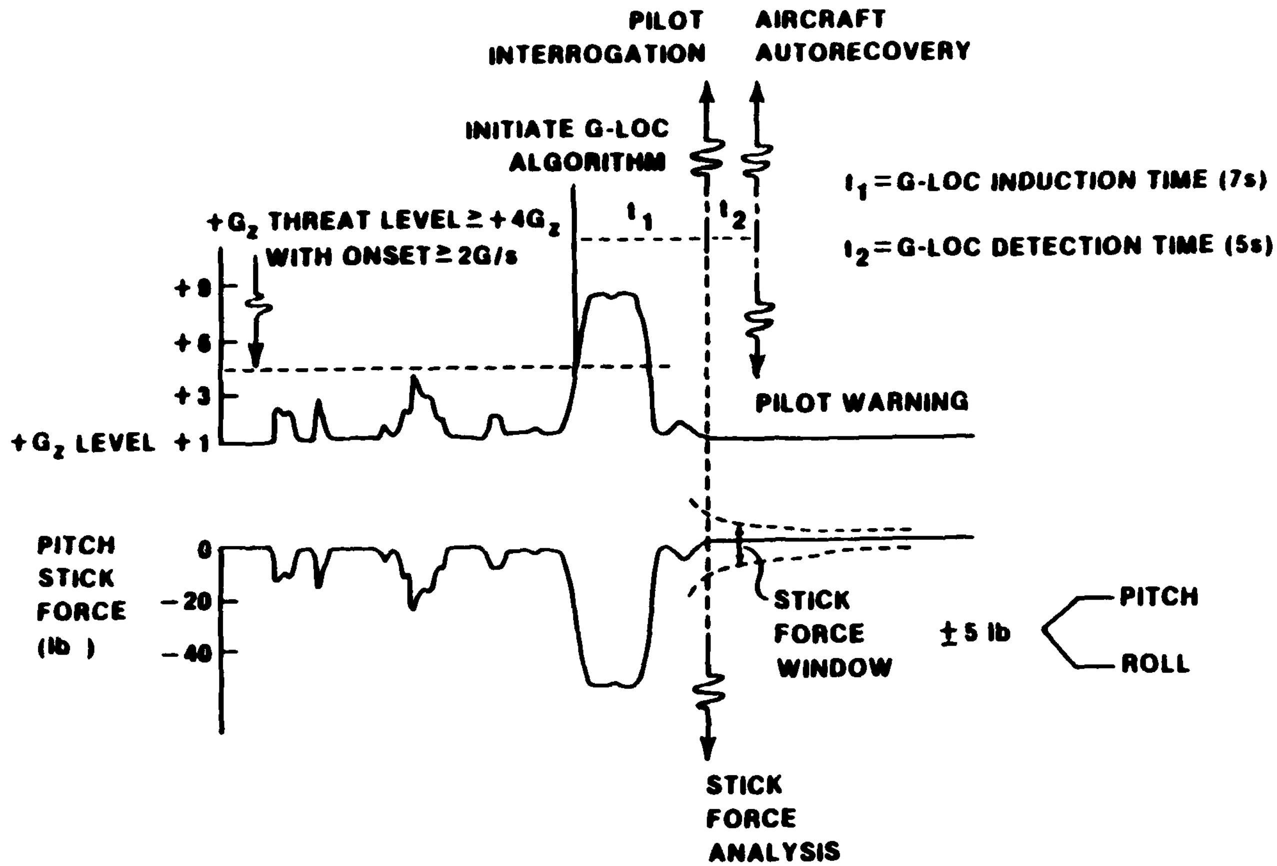

Figure 7. Physiologic autorecovery algorithm with pilot interrogation and warning based on stick-force analysis.

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